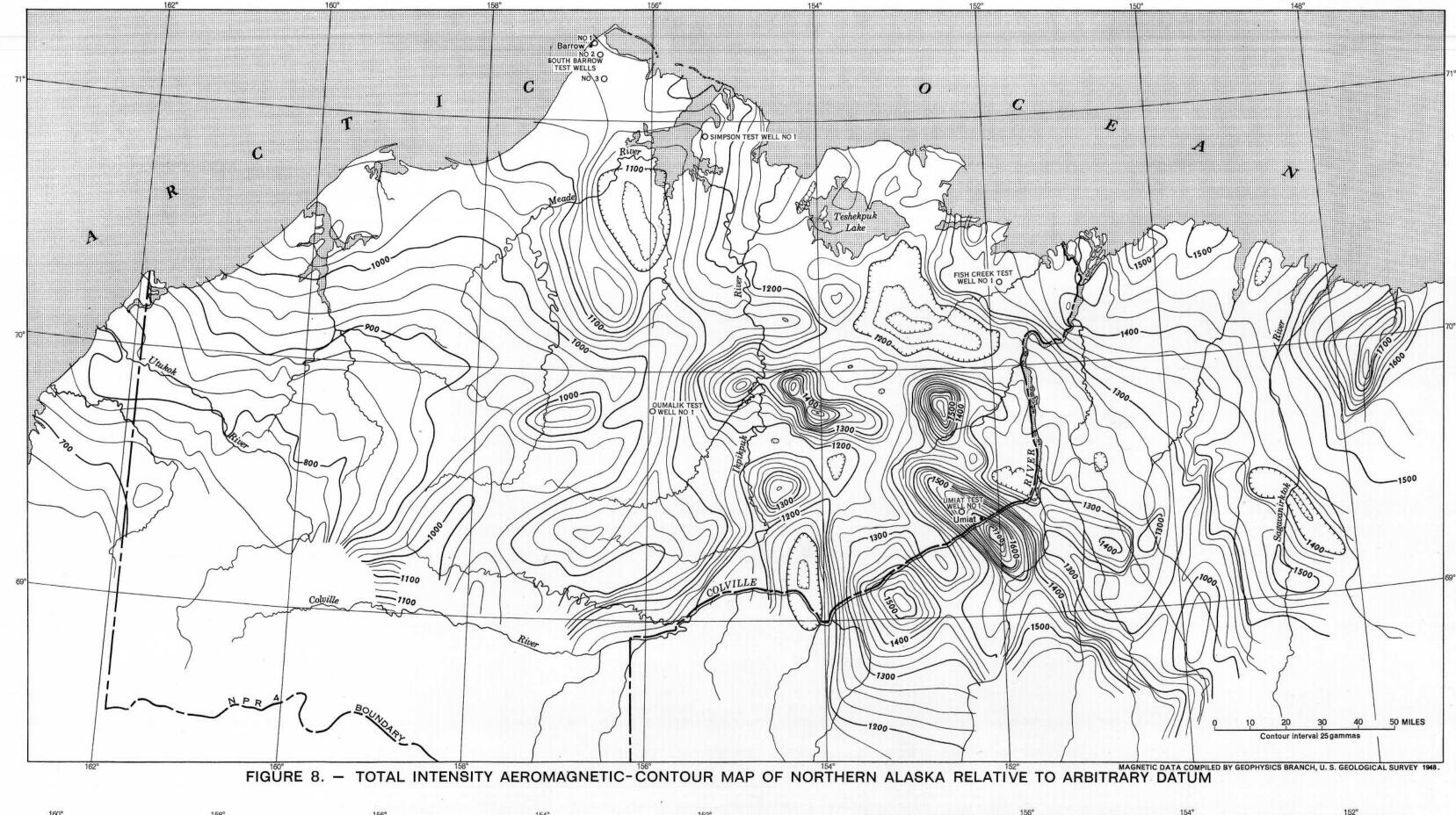
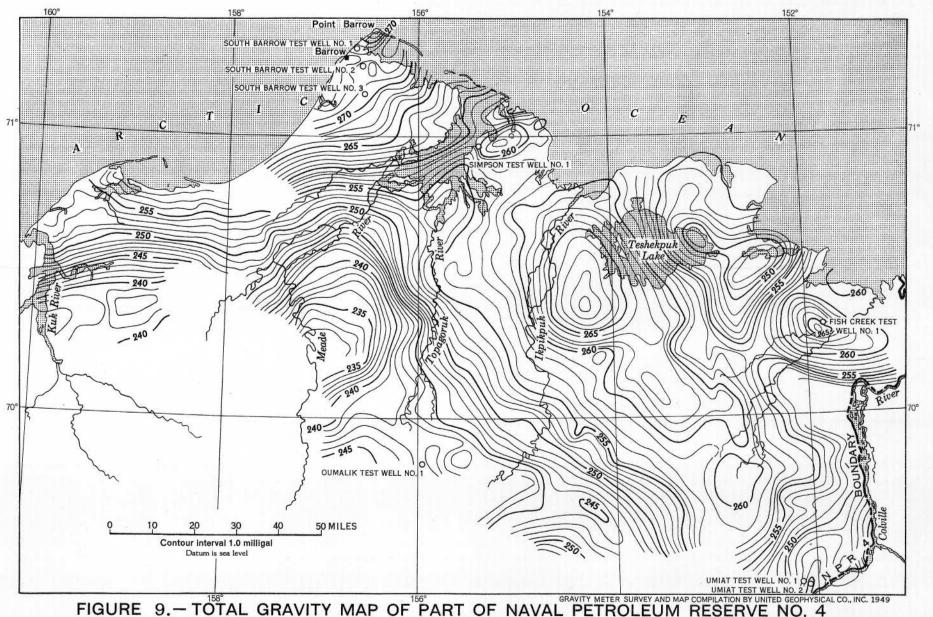
RESERVOIR CLASS

	DEPTH (feet); and LITHOLOGY	POROSITY, EFFECTIVE (percent)	PERMEABILITY ³ (md); AIR (Klinkenberg), *; OIL, K _O ; BRINE, K _D ; FRESH WATER, K _W UMIAT TEST WELL	MEMBER or FORMATION	SATURATION (percent): OIL, So; WATER, Sw; and REMARKS
1		16 (av.) 8-20,11 20, 14	<10, 17 257, 87 1.2 5.2, 2.5	Seabee Topagoruk Topagoruk Topagoruk Topagoruk	Show oil; yellow cut. Slight oil and gas odor. Show oil.
100	1,349 1,355 1,738-1,800; ss to 1,785, ss and sh below. 1,738-57	5.1 12 	1	Topagoruk Topagoruk Topagoruk Topagoruk	0il-saturated 1,738-60 ft.
	1,762-80 2,270-84; ss, sh. 2,278-84 2,297-2,348; ss	5.1-15,9	<10	Topagoruk Topagoruk Topagoruk Topagoruk	Oil, gas odor; bled oil. Oil odor 2,297-2,318 ft.; very slight show oil.
1	2,308-40 2,484-2,572; ss; sh in upper 20 ft. 2,539	5.5		Topagoruk Topagoruk Topagoruk	
:			<1-23,9.9;2.4*, 12.3* <10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	0il odor 2,670-90 ft.
	in lower 8 ft. 2,975-3,012; ss 2,981-3,009. F. D. 6,005.	4.6-13,8	2.8, 11; 0.05*, 9* UMIAT TEST WELL N	Topagoruk Topagoruk	Spotty oil saturation.
	120-130; ss, sh 235-260; ss 317-360; ss			Topagoruk Topagoruk Topagoruk	Strong kerosene odor. Kerosene odor; some thin beds oil-stained. Bled oil; gas bubbles, kerosene odor.
	320 328 387-439; ss 392 410	17 18 12	20 72 78 <10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Show oil, gas 103-345 ft. Bled oil; kerosene odor. Show oil, gas 381-444 ft.
	422. 442-455; ss, sh 444	8 10 8.7	<10 <10 <10 <10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Strong kerosene odor.
	491	14, 16 16 14 8	22*;K _b 1.9;K _W 1.8 36 270 6	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Strong oil odor. Strong oil odor.
1	525-528 760-772; ss 771 788-969; ss 789-793	10, 12	<10, 9.8	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Strong oil odor. Show oil 755-822 ft.
	796 800 802 805 824	18 (av.) 16, 17 16, 17 16	65, 164 279 187;131*;K _D 97;K _W 0.25 60* 206	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Strong oil odor. Sol7; Swl2.
	827 833-834 839	15, 13 11, 12	11 4-15,9.5 18;7.4*;Kb0.4; Kw impermeable 71	Topagoruk Topagoruk Topagoruk Topagoruk	Strong oil odor.
	939. 942. 949. 953-957 960.	11 11 11 (av.)	<10 <10 <10 <10 (av.) 4 <10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	0il odor 939-942 ft.
	979-998; ss 988 989 994	13 9 13	<10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Slight oil odor.
11	1,007 1,008 1,011 1,014-16; ss 1,020-23; ss	17 15 11 13 (av.)	<10 3 <10 (av.) <10	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	0il odor.
	1,034-36; ss F. D. 6,212.5. 100-160; ss; sh in lower 20 ft.		VMIAT TEST WELL 1	Topagoruk	S ₀ 29; S _W 49.
	220-240; ss, sh 249-294; ss, sh 251 257-261	4	106;91*,97*;K _D 70;K _W 55 50-155,89*	Topagoruk Topagoruk	Strong oil odor. Good saturation; show oil.
	273-291 329-345; ss, sh 344 348-362; ss 352	7-9.7,8.4 17, 18	465*;390*;K ₀ 295;K _w 200 13-194,84;13-176,89* 138*;K ₀ 56;K _w 37	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Good saturation. Good saturation; show oil.
	359 367-368; ss 377-378; ss 402-406; ss T. D. 571.	14 13 13	10*;K _b 5.2;K _w 4	Topagoruk Topagoruk Topagoruk Topagoruk	Oil odor. Strong oil odor.
4	919-921; ss 968-999; ss, sl 979-984 990	15	OUMALIK TEST WELL <5 34 9.7, 5.6	Topagoruk Topagoruk Topagoruk Topagoruk	Faint straw-colored cut. Faint oil stain. Faint yellow cut.
	1,195-1,205; s1, ss. 1,201 1,604-36; ss 1,606	9.6	<5 8.8	Topagoruk Topagoruk Topagoruk Topagoruk	Faint cut 1,619-26 ft.
1	1,614 1,622 1,634 1,966-67; sl 2,153-58; ss. sl.	10, 9.9 9.6 (av.) 8 (av.) 0.42, 0.36 6-15,7.5	<5 <5 <5 <5 <5	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	S _o 15-32,23; S _W 9-42,25.
1	2,756-57; ss, sl. 2,756 3,244-54; ss, sh. 3,258-60; ss, sl.	3.7, 5.9 1.8 1.6-16,6.6 9.2-15,13	<4;0.67*, 3.6*	Topagoruk Topagoruk Tuktu Tuktu	S ₀ 0.0; S _W 33; blow gas 2,736-3,498 ft. S ₀ 0.0, 5.2; S _W 17, 29. S ₀ 0.0; S _W 22, 25.
	3,490-3,500; sl. 3,752-56; sl, sh. 9,278-96; ss 9,537-52; ss, sh. 9,540	12, 6 5.9-11,8.5 4.2, 5.1	4.9;0.82-4,2.2* <1, 11 impermeable	Tuktu Tuktu Okpikruak Okpikruak Okpikruak Okpikruak	S ₀ 0.0-31,22; S _W 3.8-26,10. Pale-yellow cut 3,753 ft. Bled small amount of gas.
	9,550 9,825-40; sh, sl, ss. 10,233-50; sl, ss 10,454-68; sl I. D. 11,872.	9.2 3.4	impermeable	Okpikruak Okpikruak Okpikruak Okpikruak	Bled small amount of gas. Bled small amount of gas.
2007	115-150; ss; sh in lower 12 ft. 133	38		NO. 1 Topagoruk Topagoruk Topagoruk	Spots of yellow-green oil. Show oil, gas.
	218-220; ss. 309-310; ss. 380-404; ss	37 30, 32 21-41,35	486* 98*, 168*; K _b 74; K _w 30 11-1130,560*; K _b 94, 211; K _w 50, 78	Topagoruk Topagoruk Topagoruk Topagoruk	Sol2; Sw46. So9; Sw92. So7-59,34; Sw38-63,49; show gas.
Sec. 18. 18. 18. 18. 18. 18. 18. 18. 18. 18	445-482; ss 490-495; ss 609-623; ss. sh	32-35,34		Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Show oil; gas odor. Show oil; gas bubbles.
	818-880; ss 842 885-908; ss 920-948; ss 936	31-37,35 37 38 	392*; K _b 295; K _w 95	Topagoruk Topagoruk Topagoruk Topagoruk Topagoruk	Slight show oil. Gas bubbles.
	957-983; ss 1,077-1,370; ss, sh. 4,850-5,000; ss, sh.			Torok	Gas bubbles. Spotty oil odor.
	6,153-6,269; ss 6,535-40; ss T. D. 7,007.	17-23,19	FISH CREEK TEST WELL	Kingak Shublik	Slight show gas.
100	1,633-35 1,636-40 2,130; thin ss 2,915-3,050; sl,	28 33		Tuluga Tuluga Tuluga Tuluga Topagoruk	Faint oil stain. Oil stain. Oil stain; show oil, gas
ij	2,923 2,970 5,481; thin ss 5,508; thin ss	31 17 13	3.4* 8.9* <5;5.65*		2,925-3,060 ft. S ₀ 34; S _w 49. S ₀ 17; S _w 38. S ₀ 15; S _w 47. S ₀ 19; S _w 55.
	5,530-31; ss 5,550-60; ss 6,007-10; ss T. D. 7,020.	7.6	<5;0.83* SOUTH BARROW TEST WE	Tuktu-Torok Tuktu-Torok LL NO. 1	Faint straw-colored cut. So7.4,10; Sw31,32.
0.75	672-699; ss 1,830-1,995; ss, sh. 1,906-16	23-28,25	15, 17	Topagoruk Topagoruk Topagoruk Topagoruk Tuktu-Torok	
	2,094-95 2,335-45; ss, sh. 2,730-36; ss 2,873-76; ss 2,960-70; ss	24		Tuktu-Torok Tuktu-Torok Tuktu-Torok Torok Torok	
1	3,045-48; ss 3,078-79; ss 3,114-25; ss	13, 15	2.4*, 10*; K ₀ 0.67; K _b 1.8; K _w 1.3 4.2*; K ₀ 1.2; K _b 3.6; K _w 3.1 11*, 5*; K ₀ 6.8; K _b 7.5;	Torok Torok Torok	S ₀ 13; S _W 39. S ₀ 13; S _W 28. S ₀ 26; S _W 31.
	3,130-32; ss 3,150-54; ss 3,160-63; ss 3,184-86; ss 3,195-98; ss	18, 17 18 14	Kw4.9 <4 24, 10 62 7 <5	Torok Torok Torok Torok Torok	Bled oil and gas. Show oil. Slight show oil. Show oil. Bled oil.
	3,276-77; ss 3,310-41; ss, sh. T. D. 3,553.		SOUTH BARROW TEST WE	Torok Torok LL NO. 2	
	1,299-1,300; ss 1,762-64; ss 1,772; thin ss 1,999; thin ss 2,023-25; ss	24 24 16	50 8.2 14 19 67;18*;K ₀ 6.9;K _b 4.5; K _w 1.8	Topagoruk Torok Torok Torok Torok	Dark-brown viscous cut. S ₀ 21; S _W 35.
	2,047; thin ss 2,056; thin ss 2,111; thin ss 2,124; ss 2,126-28; ss	20 9 18, 20 18	6.8 12 <7 40*; K ₀ 7.8; K _b 7.6; K _w 4.3 25	Torok Torok Torok Torok Torok	Oil saturated. Dark-brown oil in cut. Dark-brown oil in cut. Sol3; Sw57. Sol3; Sw57.
	2,170; thin ss 2,176; thin ss 2,188; thin ss 2,198; thin ss	7.3 6.4, 10	37*; K ₀ 4.9; K _b 1; K _w 1 0.57*; K ₀ 0.42; K _b 0.04; K _w 0.03 4.8	Torok Torok Torok Torok	S ₀ 13; S _W 45. S ₀ 17; S _W 45. Oil stain. Oil stain.
	2,227; thin ss 2,229; thin ss 2,254; thin ss 2,286;88; ss 2,330-33; ss	5.5 16 (av.) 12 (av.) 9-19,17	<8 49 9 <8-104,60 33-108,72	Torok Torok Torok Torok Torok	Oil odor. Oil stain and odor. Oil stain, oil odor. Blow
	2,346-47; ss 2,356; thin ss 2,375; thin ss 2,378; thin ss	7.8-9.2,8.5 21 22	<9 <9 18 19	Kingak Kingak Kingak Kingak	gas 2,312-91 ft.
	2,383; thin ss 2,397; thin ss 2,404-06; ss, sh. 2,416; ss, sl, sh 2,430; ss, sh T. D. 2,505.	16 19 (av.) 15.4	91 6 8.3 5.7 (av.)	Kingak Kingak Kingak Kingak Kingak	Slight oil stain. Blow gas 2,381-2,443 ft. Slight oil odor. Slight oil odor.
	200-220; ss 224-230; ss 229	29, 28	SOUTH BARROW TEST WE 390, 199 	Topagoruk Topagoruk Topagoruk	Straw-colored cut. Amber cut, 224 and 229 ft
	1,210-22; sh, ss. 1,739-58; sl, ss. 1,758-98; sl, ss. 1,758-78	14 (av.) 11-19,15 15-19,16	0.9-125,28* 0.61-24,5.2*	Torok Kingak Kingak Kingak Kingak	S ₀ 2.6, 8.5; S _W 83, 85. S ₀ 8.1-21,12; S _W 38-67,53. Fair to good oil odor. S ₀ 4.6-17,9; S _W 20-71,47.
	2,430 2,645-55; sl 2,651 2,761-70; ss	9.3	7.8 <5	Kingak Kingak Shublik Shublik Shublik Shublik	Yellow cut at 2,646 ft.
	2,766 T. D. 2,900.	10		SHUDIIK	

- Permeability, unless otherwise designated, is air permeability measured by the U. S. Geological Survey with the manometer permeameter or the Hayward permeameter. Air permeabilities (Klinkenberg) were determined by S. T. Yuster, as were all liquid permeabilities.
- 4. All saturation determinations were made by S. T. Yuster.
- 5. Where more than two determinations were made, the range and average are given: 6.1-17,11.





-20,000

Silty graywacke

trace

Permeability (Klinkenberg) 138 mg

Fresh-water permeability 37.5 r

isible porosity 12% (microsco

incipal mode of visible pores

mount of wall area clay-coated

Brine permeability 56.5 md.

Contour interval 250 and 500 feet

Datum is sea level

FIGURE 10. - STRUCTURE-CONTOUR MAP DRAWN ON THE TOP OF THE BASEMENT

Normal graywacke

Topagoruk Torok (strongly Topagoruk consoli-

14.4 14.5 14.0 12.95 12.8 24.7 13.17 6.0 ... 2.57

Permeability (Klinkenberg) 390 md.

resh-water permeability 200 md

sible porosity 15% (microscopic)

Amount of wall area clay-coated 10%

3rine permeability 295 md

test wells

TABLE 2. AVERAGE (ARITHMETIC MEAN) OF TEXTURE. COMPOSITION. AND RESERVOIR CHARACTERISTICS OF MAJOR PETROGRAPHIC CLASSES OF GRAYWACKE

26.3 11.0

8.3 3.4 3.0 4.2 16.5 2.7 2.0 2.6 4.6 24.0 1.3 1.3

37.0 69.0 73.3 64.9 40.0 73.0 58.0 72.0 71.6 34.0 84.0 86.8

Average of three samples.

Well-developed quartzose graywacke (almost a protoquartzite), an excellent reservoir rock, at 344 feet, Umiat

core test No. 1. Picture showing a particularly porous area with one extra-large pore.

6. Average of three unconsolidated samples.

SOUTH BARROW TEST WELL NO

SOUTH BARROW TEST WELL NO 2

-4,000

is interpreted as being at the BARROW TEST WELL NO 3

North of line, basement surface

is approximately at the top of ...

Number of samples

Sand, principal mode (mm)...

COMPOSITION (percent)

Volcanic rock fragments.....

Effective porosity (percent).. Air permeability (md)3......

Visible pores (percent of

Percent of clay-coated wall

 Brine permeability (md).......
 150
 6.0

 2.5'

 Fresh-water permeability
 79
 3.4

 1.97

 after liquid flow (md).....
 183
 29.4
 ...
 10.47

 Visible pore size (microns)...
 64
 34.0
 30.3
 37.7

1. Some of the porosity and permeability averages for calcareous graywackes

2. Clay minerals and hydromicas in general were differentiated and counted

and South Barrow siltstones are based on fewer samples than shown.

on the basis of combined microscopic and X-ray spectrometer data.

3. Air permeability (and corresponding porosity) was measured by the U. S. Geological Survey Fairbanks Laboratory; all other permeability and

porosity were measured by S. T. Yuster, University of California at

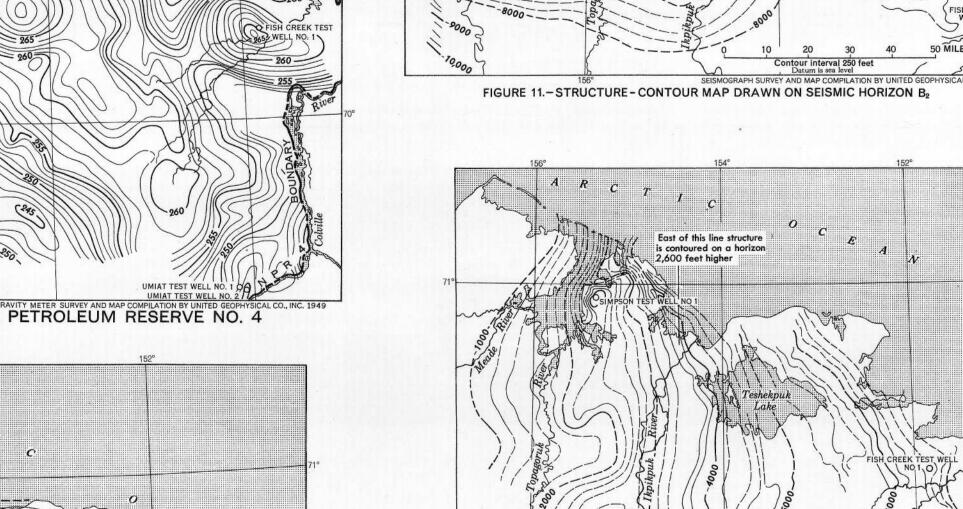
Montmorillonite2...

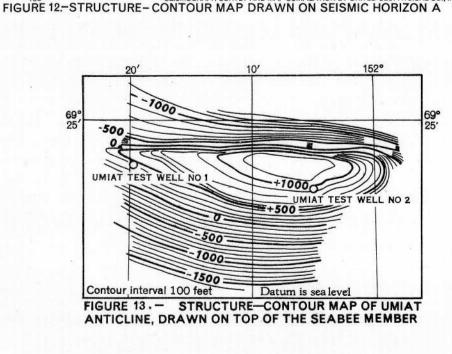
Carbonate cement ..

Miscellaneous cements.

Silica cement.

the zone of steep and erratic dips





S. Barrow No. 2, 2,430'

S. Barrow No. 2. 2.198'.

S. Barrow No. 1, 3,115.5'.

Porosity 13%. Permeability 10.6 md.

S. Barrow No. 2, 1,762'.

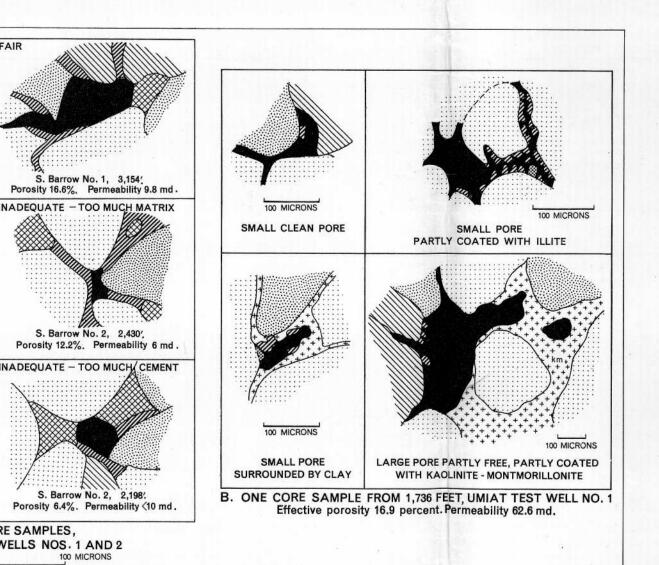
Porosity 24.4%. Permeability 8.2 md.

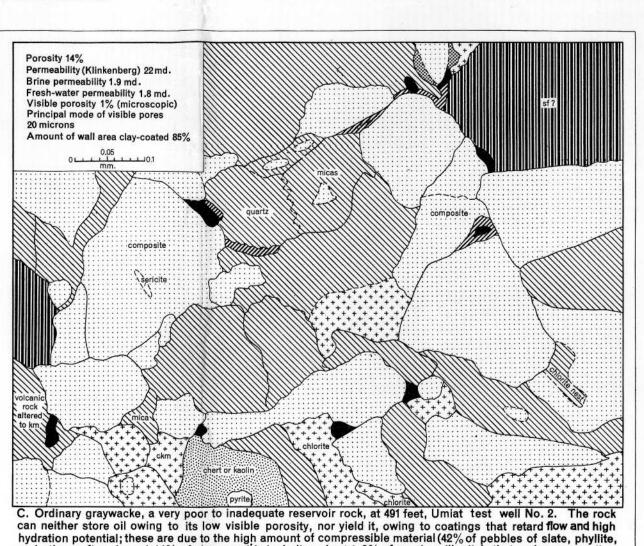
A. DIFFERENT CORE SAMPLES,

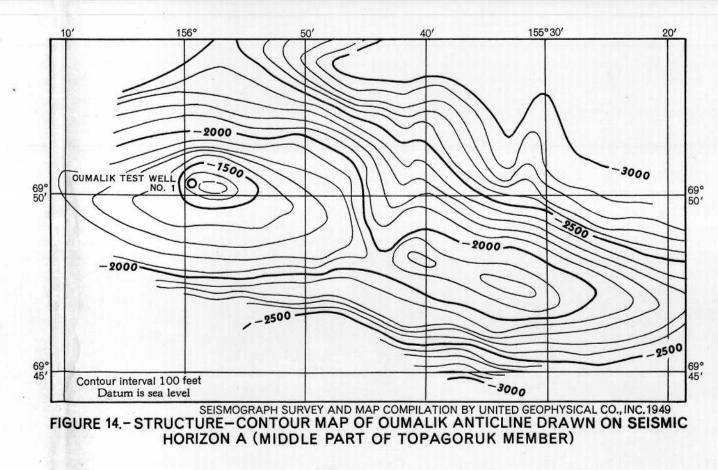
SOUTH BARROW TEST WELLS NOS. 1 AND 2

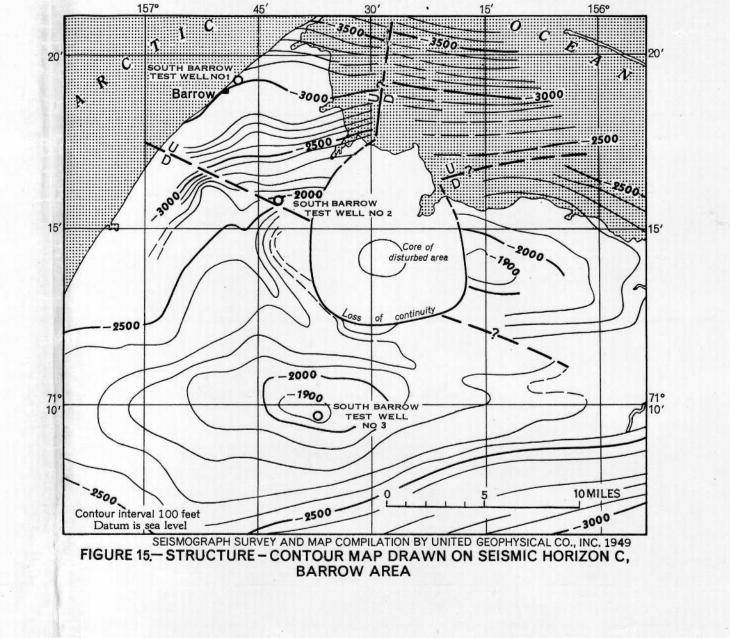
INADEQUATE - TOO FINE

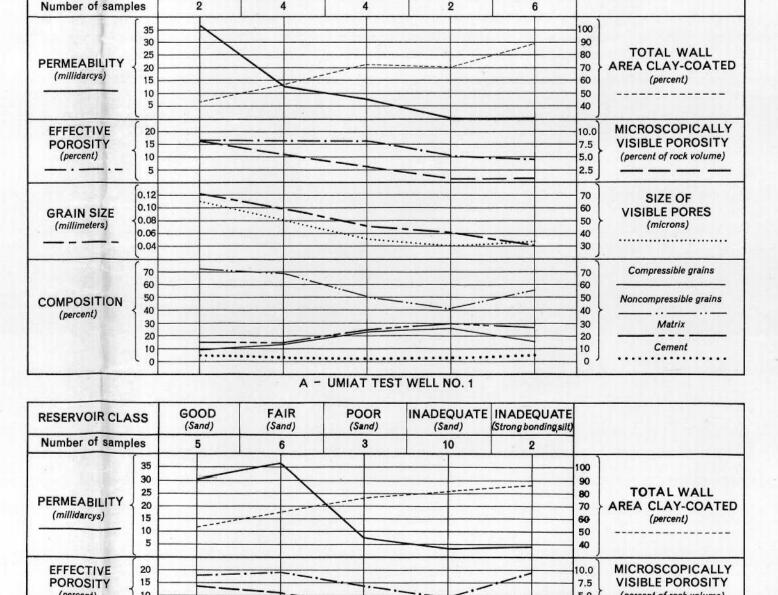
siderable hydration potential, owing to the presence of some montmorillonite.

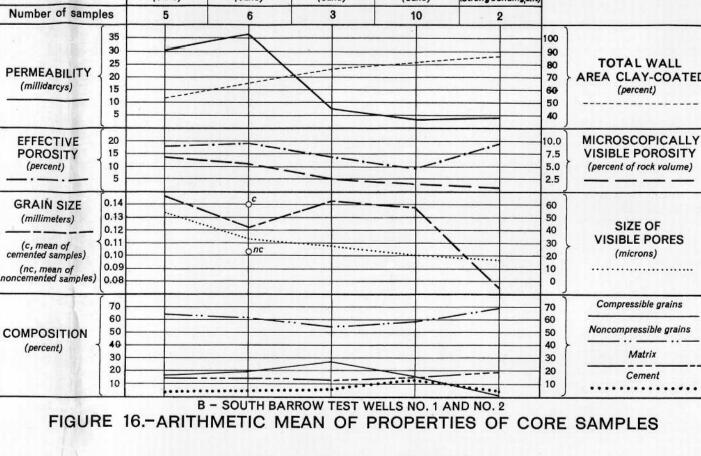












EXPLANATION

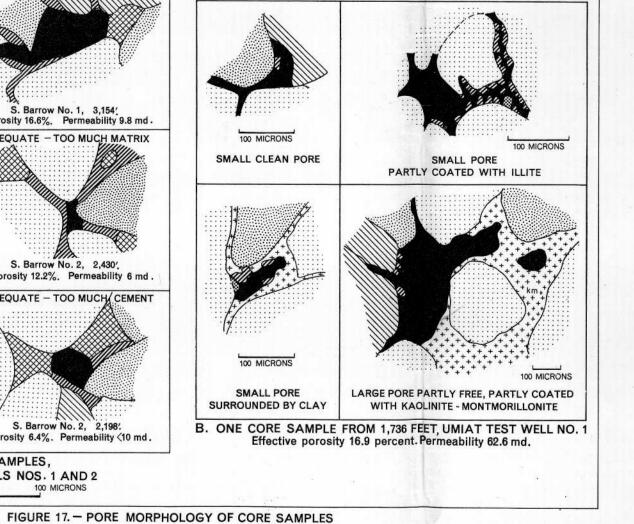
for figures 17 and 18

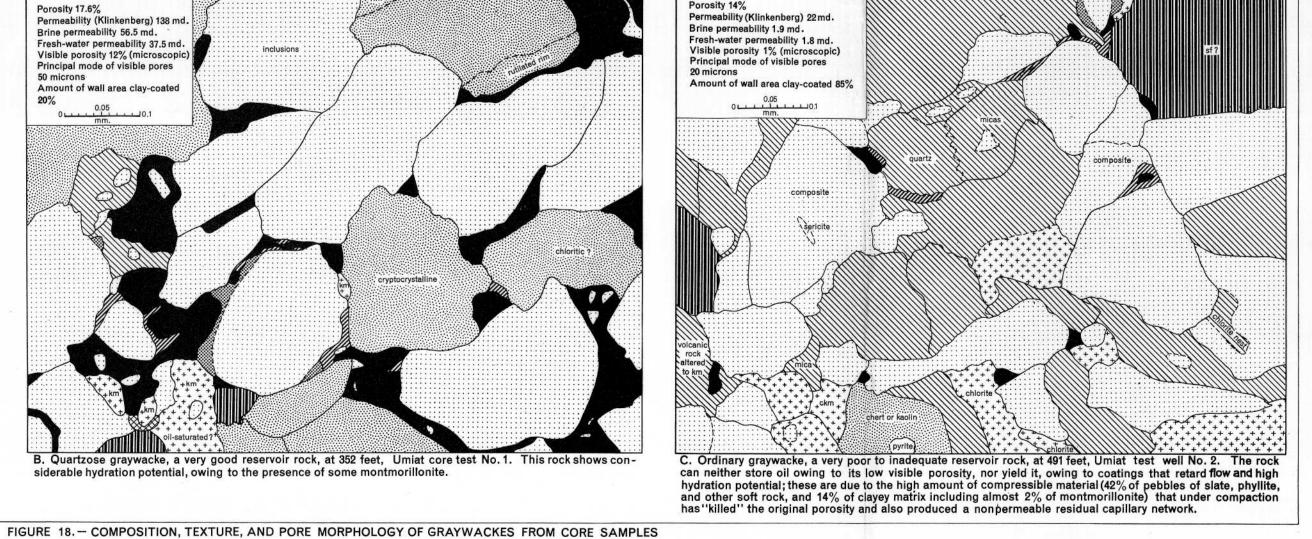
Rock fragmer

Secondary silica

Feldspar, undifferentiated (Sericitized feldspar, sf)

Carbonate, undifferentiated





GEOLOGY OF THE ARCTIC SLOPE OF ALASKA

This report presents results of exploration in Naval Petroleum Reserve No. 4 (NPR-4) conducted by the Navy Oil Unit of the U. S. Geological Survey n cooperation with the office of the Director, Naval Petroleum and 011 Shale Reserves. Lack of space does not permit complete documentation and acknowledgments. The petroleum exploration program started in 1944 and 1:

continuing. Information presented here is based on data obtained to 1950: however, the location of test wells and core tests completed or being drilled in March 1951 are shown on the geologic map, sheet 1. The geophysical maps on sheet 2 show only the test wells that were drilled at the time those maps were made.

> GEOPHYSICAL SUMMARY By Stephen W. Dana

The main objective of geophysical exploration in NPR-4 has been to find and to delineate possible oil-bearing structures in the coastal plain area. The potential oil-bearing rocks of the coastal plain are almost everywhere overlain unconformably by a blanket of unconsolidated Pleistocene sediments (Gubik formation). Hence geophysical surveying offers the only means of outlining regional and local structures of this part of the Reserve. Much of the geophysical work to date has been of a reconnais-Most of the Reserve has been surveyed with the airborne magnetometer by the Geophysics Branch of the U.S. Geological Survey. Seismic surveying, both reflection and refraction, has been and is being done by the

ited Geophysical Company, Inc., under contract to the U. S. Navy. This

company has also done considerable gravimetric surveying in the northern part of the Reserve. The gravity surveying has been facilitated by flying the gravimeter from one observation point to another and by using the eleconic altimeter for altitude control. MAGNETIC SURVEY

The results of the airborne-magnetometer survey are shown in figure 8. This figure has been reduced and recontoured from the original 1:500,000 map which had a 10-gamma contour interval. The map exhibits positive regional gradients to the north and northeast considerably in excess of the dipole gradient produced by the earth as a whole. These reflect in a general way the northward thinning of sedimentary rocks predicted in 1945 from analysis of magnetic anomalies in the Cape Simpson area and verified by subsequent seismic work and drilling. The most pronounced feature in figure 8 is the band of prominent magnetic highs extending from Umiat northwest through the seismic high between the Meade and Topagoruk Rivers to the Point Barrow area. An extensive quantitative analysis of all these anomalies has not been attempted thus r, but by the use of mathematical models and depth rules it has been possible to obtain rough estimates of depths to magnetic rocks. Such analysis of the Umiat anomaly yields a depth of about 20,000 feet; of the magnetic high between the Topagoruk and Meade Rivers, a depth of 15,000 feet; and of se magnetic feature 3 miles east of the 157th meridian and between the Meade and Inaru Rivers, a depth of 10,000 feet. The amplitude and breadth of these anomalies suggest that they are produced by the relatively high magnetic susceptibility of rock masses probably crystalline in character intrusive in origin, and batholithic in size. Although these rock masses may rise as erosional remnants above the general level of the basement surace, the magnetic anomaly is more probably produced by the susceptibilit netic highs within it are flanked on the northeast side by well-defined magnetic lows, and on the southwest side by flatter gradients and less conspicuous lows--the usual concomitant of induced magnetism in rock formations in high magnetic latitudes. Prominent anomalies are absent in the extreme north part of the aeromagnetic map. The magnetic profiles, however, indicate clearly two 20-gamma anomalies (too minor to show on fig. 8) east of South Barrow Test Well No. 2--one on the eastern and another on the western flank of a grav ity high. Analysis of the magnetic data yields a depth to the crystalline basement of 2,600 feet. In the Cape Simpson area, the original profiles in the vicinity of lat. 71° N., long. 155° W. show a high of about 25 gammas, and the estimated depth for it is between 7,000 and 8,000 feet.

GRAVITY SURVEY Results of the gravity survey work through the 1949 field season are presented in figure 9 as contoured isogam lines expressing the Bouguer anomalies. This means that the "free-air" correction, Bouguer reduction, and latitude correction have been subtracted from the observed relative gravity readings and the results plotted as lines of equal intensity. T coastal plain area of the Reserve is so flat that terrain corrections are

The anomalies in both the Point Barrow and Cape Simpson areas correlate well with gravity and seismic data, and are believed to reflect basement

In a few areas the Bouguer anomaly highs and lows correspond to seismic and magnetic highs and lows, but in most of the region surveyed with the gravimeter there is no such coincidence. One of the more interesting examples in which a gravity high coincides closely with seismic and magnetic highs is in the Point Barrow area (fig. 9). This gravity high culminates just east of South Barrow Test Well No. 2. It is circular in ou line, quite broad in areal extent, and is surrounded by a belt of rather sharp gravity lows. Seismic studies indicate that this is an area of a prominent basement high, bounded by peripheral faults, the basement rocks having deep and erratic dips. The belt of gravity lows corresponds to the zone of peripheral faults. This circular zone of deformation and associated gravity and magnetic anomalies seems to be a structure of cryptovolcanic type that may have been caused by an igneous intrusion into basement rocks or by the impact and presence of a large meteorite. Particular trends in the characteristics of the gravity anomalies mapped to 1950 do not indicate the nature of geologic structures or conditions causing those anomalies. Various geologic conditions may be postulated to explain the lack of coincidence between gravity and other geophysical anomalies.

SEISMIC SURVEY Up to 1950 detailed reflection seismic surveys had been made on structures in the areas of Point Barrow, Cape Simpson, Fish Creek, Oumalik, Umiat. Smith Bay, the Meade River, the Ikpikpuk River, and the Topagoruk River. In the rest of the coastal plain the seismic work has consisted o long reconnaissance traverses that outlined regional trends. The reflection surveys have been supplemented by refraction studies, particularly in the area extending southwest from Point Barrow to the vicin ity of Skull Cliff and south to the lower Meade River district. These refraction profiles indicate the existence of an extensive series of basement rocks with an elastic wave velocity that averages about 17.000 feet per second. Core samples from the bottoms of four test wells (South Barrow Test Wells Nos. 1, 2, and 3, and Simpson Test Well No. 1) show that the top of this basement series includes argillite and slate. Figure 10 is a contour map drawn on the top of the basement. Several refraction profiles in the vicinity of Point Barrow and Cape Simpson have recorded velocities of about 21.000 feet per second below the top of the argillite and slate sequence, which may indicate the presence of granite at greater depth. In the area of the Barrow and Simpson test wells steep and erratic dips within the basement rocks have been recorded by reflection shooting The top of the basement rocks (fig. 10) here corresponds with the upper limit of the steep and erratic dips and with horizon D, which is at the base of the Mesozoic sequence. These dips disappear to the south, where gently south-dipping conformable strata below horizon D extend down to the lower limit of acoustic horizons. Two possible explanations of the southward disappearance of the steep and erratic dips below horizon D are: (1) If it is assumed that the steeply dipping argillite-slate sequence in the Barrow and Simpson areas is of pre-Cambrian age, as regional geologic erpretations suggest, then the continuous and conformable rocks underlyng horizon D south of the area of erratic dips may be a series of Paleozoic rocks that overlap and wedge out northward against the pre-Cambrian argillite and slate. Presumably rocks equivalent to the basement rocks in the Barrow and Simpson areas lie below the lower limit of acoustic horizons in (2) The steep and erratic dips in the Barrow and Simpson areas are the

result of local deformation by intrusions or by orogeny. According to this explanation, the conformable rocks beneath horizon D to the south in the undisturbed region are either Paleozoic or pre-Cambrian and are the time equivalent of the deformed argillite-slate sequence to the north. The cal subbasement velocities of 21,000 feet per second in the Barrow and Simpson areas lend some support to this explanation by suggesting the presence of crystalline plutons below the argillite-slate sequence.

Several other seismic horizons have been used in delineating structure. tures in the coastal plain. These are all shallower than horizon D dis cussed above. Contour maps of two horizons--B2 and A--are shown as figures l and 12 respectively. Horizon B2 is about at the top of the Jurassic and Triassic rocks. Although it has not been extended over as large an area as horizon D. owing to the poorer quality of the data for this horizon, enough information is available to outline the prevailing southerly dip of horizon B2 as shown in figure 11. The configuration of horizon B2 approximates that of the underlying horizon D except that the south dip of B2 is not as pronounced as that of the stratigraphically lower D. This means that the rocks between horizons B2 and D, presumably Triassic and Jurassic, gradually increase in thickness southward from the basement structural high in the

Horizon A, contoured in figure 12, is within the Nanushuk group (Cretaceous). In the vicinity of Teshekpuk Lake anomalous dips occur in strata near horizon A, so control for the contouring here is based on a datum 2,600 feet above horizon A. The significant features of the map of horizon A are the pronounced anticline in the Oumalik area in the southwest part of the map and the east to slightly southeast dip in the entire region from the Topagoruk River almost to the Colville River. This regional trend is anomalous with respect to the prevailing south dip of the underlying hori zon B2, but may be explained by the fact that seismic evidence indicates a possible regional unconformity slightly above horizon B2. Considerable difficulty has been experienced in correlating the seismic horizons from area to area. This is due to the lack of complete cover-

age of the coastal plain by seismic work, to the lack of good reflection data in some regions, and to the sparsity of test wells. Areas in which the Cretaceous strata have initial dips, commonly 5° to 10°, are recorded by seismic work; tracing of seismic horizons through such areas may lead to error. Because of these factors it must be recognized that horizons such as B2 and A may in places cut across stratigraphic units and, if so, they do not represent a completely accurate picture of the structures above the basement rocks in the Coastal Plain of the Reserve.

> STRUCTURE By William A. Fischer

The structural features described here and shown on the geologic map fig. 1) have been studied by surface and subsurface methods. Subsurface studies, including extensive seismic surveys, in general are limited to the Arctic Coastal Plain province. Studies of the mountains and 'oothills provinces are based on a combination of field observation and geoogic interpretation of aerial photographs. Aerial photographic coverage of northern Alaska is excellent. BROOKS RANGE PROVINCE

The contact between Paleozoic rocks, which make up the major part of the mountains, and Mesozoic rocks of the foothills is believed to be in large part a fault contact. Along the north front of the Brooks Range imbricate thrust plates and overturned faulted folds are prevalent; these folds strike east and dip 20°-40° S. Common features are thrust faults, which tend to steepen southward toward the heart of the Range; reverse faults. which follow either the axial planes of overturned folds or the less competent of the Paleozoic strata; and tear and (or) normal faults many of which extend more than 10 miles into the Range. Horizontal displacement along the tear and (or) normal faults generally is not great, but vertical displacement in some places is several thousands of feet. East of the Anaktuvuk River many of the major tear and (or) normal faults are believed to extend north of the Range into the foothills.

The central part of the mountain area, in the vicinity of the headwaters of the Ipnavik River, is marked by a regional topographic saddle Peaks in this area are lower and more rounded than those to the west and east, and the Lisburne limestone of Mississippian age is believed to be mostly absent. This topographic saddle may be due to local conditions of lithology or structure that caused less resistance to erosion, to lesser original thickness of the Paleozoic rocks, to greater erosion because of

variations in drainage, or to a combination of these conditions. Within he foothills just north of this saddle the degree of deformation is greater than that in similar structural positions to the east and west. East of the Sagavanirktok River the sharp en echelon mountain front is believed to have been shaped by a combination of (1) east-striking faults (south sides upthrown), most of which are thrust faults but some of which may be normal faults, and (2) north-striking or transverse faults believed include both tear and normal movement. Within the blocks of Paleozoic cocks that extend northward in echelon arrangement the strike of the strucsures is east. The Mesozoic rocks adjoining the western margins of these locks strike north of east, with the north component increasing eastward ward their contact with the blocks of Paleozoic rocks. The change or il" in strike within the Mesozoic rocks may be explained by drag along major tear faults or by diminishing west tilt of Mesozoic strata on the west sides of normal faults that are downthrown to the west. The northern margins of the northward-projecting blocks of Paleozoic rocks are thrust for short distances out over the Mesozoic rocks.

Southern Foothills section. -- Most of the outcropping rocks in the Southern Foothills section of the Arctic Foothills province are Mesozoic in ge. In contrast to the Brooks Renge, compressional stress was here releved more by folding than by faulting, and resulted in elongate parallel olds, such as the Castle Mountain syncline in the more competent sandstones of the Okpikruak and Torok formations, and small tight folds and minor faults in the less competent shales of these and older Mesozoic formations The north limbs of the anticlines are normally steeper than the south limbs. West of the Anaktuvuk River the anticlinal axes strike a few degrees north of west. East of the Anaktuvuk River the strike is almost due west. Many of the major folds are cut by thrust or reverse faults.

ARCTIC FOOTHILLS PROVINCE

A study of aerial photographs has indicated a huge synclinorium paral lel to the front of the mountains in the area between the Killik and Utukok Rivers. North of this synclinorium and apparently continuous with it are two anticlinoria and one synclinorium. The northern synclinorium probably is related to a depositional trough in which the coarse, poorly sorted sedi ments of the upper part of the Torok formation were deposited. The northern anticlinorium lies within the belt of Torok outcrop, and, although little structural information is available, the Lisburne limestone is believed lie within a few thousand feet of the surface at the axis of the fold. The northernmost synclinorium and anticlinorium seem to be structurally similar to the Castle Mountain syncline and the Ayiyak anticlinorium, which are east of the Killik River, but these structures are not believed to be lirect continuations of the structures west of the Killik River. East of the Anaktuvuk River the Mesozoic rocks strike east and intersect the mountain front as it swings sharply to the north in the vicinity f the Sagavanirktok River. In this area they seem to abut against the mas-

but that they have since been raised and eroded from the mountain areas. Northern Foothills section. -- The anticlines within the Northern Foothills area in general are characterized by their lateral persistence and by their tendency to bifurcate and enclose cance-shaped synclines. Flank dips average 6°, but dips on the north limbs of some anticlines exceed 20°. West of long. 157° W. many of the anticlines in strata of the Nanushuk oup, such as the Archimedes Ridge anticline, are breached to the underlyg Torok formation. Because of the intense folding of the Torok formation long the crestal zones, the anticlinal axes as mapped are probably correct or the competent Nanushuk group that has been stripped off, but do not secessarily show correctly the structure of the incompetent Torok formation that crops out at the surface in the anticlinal valleys. These mapped axes

are thus "phantom" axes of folds in the Nanushuk group, which have been

sive Paleozoic rocks. A normal fault upthrown on the east side parallels

he north-trending mountain front in this area; it is probable that the

Mesozoic rocks were deposited over the Paleozoic rocks east of this fault.

On large-scale maps that show structural detail of the foothills area, lisplacement of large segments of bedrock is shown by offsets of the major east-striking structures along zones or lines that strike N. 20° E. in the western part of the area, through north in the central part, to N. 25° W. n the eastern part, in the vicinity of the Canning River. From the Anaktuvuk River eastward these lines are believed to be faults that in general control the courses of the major rivers. In the area west of the Anaktuvul liver these zones or lines are represented by alinements of minor faults of bends in the structural axes. These offsets or bends in the anticlinal rends coincide with structural lows on the axes and were caused by differ ential northward movement of segments bounded by the zones or lines of off-The structural bends and corresponding lows indicate that the differential movement took place during folding, and that either the amplitude of folding within the bend area was lessened by stretching or that compressional forces, during or after differential movement, acted more strongly on the segments of the axes that were more nearly normal to the direction

Between the Meade and Nanushuk Rivers the regional plunge of anticlines in the Nanushuk group is east. Local west plunge, although probably present on most of these anticlines, can be proved in only a few places. Between the Sagavanirktok and Canning Rivers the regional plunge is west. his results in a general structural depression centering between the Nanuhuk and Sagavanirktok Rivers and in a southward projection of younger rocks, including Tertiary. Several anticlines, such as the Kigalik and Awuna, are faulted at the surface near the axes. Longitudinal faults in foothill structures are more common in the central part of the province than they are to the east or west. The elongate nature of the folds has led to speculation that they may be faulted at depth, with the fault planes approximately following the In the Northern Foothills section the distance between anticlinal axes

remains almost constant, that is, about 7 miles. There is a slight and somewhat erratic decrease in amplitude of folds and also in abundance of faults northward from the southern margin of the section. The asymmetric Umiat anticline was mapped from surface exposures (fig.) and further detailed by seismic studies. Closure is believed to exceed 00 feet. On the south limb the dips average 6°; the north limb is steepened by a sharp monoclinal flexure parallel to and slightly north of the axis over the greater length of the anticline. Outcropping strata on either side of this flexure do not show significant evidence of major displacement but some surface and subsurface evidence suggests that the flexure may be aulted. A study of electric logs of the Umiat test wells indicates a possible repetition of section along the south flank, which is interpreted as representing a thrust fault. The inferred fault may or may not come to the surface along the flexure on the north flank. The Oumalik anticline (fig. 14) is just north of the northern limit of

outcrop of Cretaceous rocks; all structural information, therefore, is from subsurface studies. The north limb is somewhat steeper than the south, this difference decreasing with depth. The structural saddle between the two highs shown on figure 14 disappears at depth and only one area of closure is evident on seismic horizon B. The structure contours as drawn on eismic horizon A (fig. 14) show a closure of 500 feet; below this horizon the dips steepen and closure increases to a minimum of 900 feet at seismic horizon B. Seismograph profiles indicate a continued steepening of the beds at greater depth on the north flank. At approximately 10,000 feet the north-dipping beds on the north flank rest unconformably on beds having a regional south dip. This angular difference decreases northward. ARCTIC COASTAL PLAIN PROVINCE

Northward from the southern margin of the Arctic Coastal Plain province the amplitude of the folds decreases, but the folds maintain the general regional strike. North of approximately lat. 70° N. the beds become largely flat lying; such structures as are present are of "amoeboid" type, varying to a large degree in strike and over-all extent and outline. Approximately 10 miles southeast of Barrow seismograph studies have delimited a complex core of basement rock (fig. 15) that extends to within pproximately 1,200 feet of the surface. This core is roughly circular. is about 5 miles in diameter, and is bounded by a peripheral fault or faults. dditional high-angle faults radiate from it. There is some evidence of runcation of the conformable beds on the sides of this core. Seismic studies have outlined two closed anticlines on the margins of this area of deformation. Both these anticlines persist in some degree through all seismic horizons. Closure on the east structure is controlled by the peripheral faults surrounding the central core. Seismic profiles Indicate that the faults surrounding the area of disturbance are downthrown on the inner side; if this is true, the core probably once extended higher than it now does, but it subsided or settled to its present depth at some time prior to the deposition of the conformable sediments now covering it.

> SUMMARY OF CORE ANALYSIS RESULTS Professor of Engineering University of California at Los Angeles

Core-analysis studies of samples from drill holes in NPR-4 were made at the School of Mineral Industries of The Pennsylvania State College and the Department of Engineering, University of California, Los Angeles. addition to porosity and permeability studies made under the author's supervision at these institutions, the U. S. Geological Survey has made numerous porosity and permeability determinations at its laboratory in Fairbanks, Alaska, which are included in table 1.

Sandstone cores from Umiat Test Wells Nos. 1, 2, and 3 have an average porosity (table 1) of 13.6 percent, and those from South Barrow Test Wells os. 1, 2, and 3, 17.3 percent. The average porosity of cores from Simpson Test Well No. 1 is 33.4 percent, from Oumalik Test Well No. 1, 7.8 percent, and from Fish Creek Test Well No. 1, 19.1 percent. Porosity measurements on samples from NPR-4 must be considered with caution as the sands contain clay minerals that swell in the presence of aqueous solutions, thereby reducing the volume available for flow. In the subsurface the minerals are in contact with connate water and occupy a larger volume than they do when dry. Tests on some core samples from NPR-4 indicate an approximate increase of about 5 percent in the volume occupied by the wet mineral grains. This represents an upper limit to an absolute correction on porosity. For example, a sample having 25 percent porosity when dry may have a porosity of about 20 percent if in contact with connate water. No completely adequate test has been devised for determining porosity under reservoir conditions; all tests are made on dried and extracted

One type of permeability test made under the writer's supervision was the Klinkenberg, in which the permeability is determined with air at a series of mean pressures and extrapolated to infinite mean pressure. Theoretically, this extrapolation represents the ideal liquid permeability, as suming no reaction between the flowing fluids and the porous medium. The clay minerals. however, tend to swell in the presence of aqueous solutions and in so doing reduce the size of the pores available for flow. The efect of such action on permeability could be enormous, inasmuch as the ability of the sand to conduct fluids varies as the fourth power of the capillary radius. Because of this reaction, it is necessary to run tests using aqueous media, which give considerably lower permeabilities. The sequence used was first, Klinkenberg; second, brine, a solution of sodium chloride made up to a concentration of 10,000 parts per million of chloride ion; and third, fresh water. In some tests reduction in permeability was as great as 70 percent in going from air to brine as the flowing medium. In testing fresh-water permeability, some of the samples were completely plugged llowing no passage of liquid. Some samples reacted to the extent that they disintegrated in the presence of the aqueous media. In the field this would manifest itself in a caving action in the well, which could be troublesome. The results of permeability sequence studies of cores from wells in

NPR-4 are as follows:

PERMEABILITY

Well	Permeability change (air (Klinkenberg) to brine to fresh wate
Umiat Test Well No. 2	normal decline. normal decline. normal decline. very drastic decline.
Simpson Test Well No. 1	normal decline.
aqueous phase. In addition to bility, tests of the effect of	ity of determining permeabilities with an determinations of the aqueous-phase permeabil on permeability were made on some samand in fair agreement with the relative peable in the literature.
produces a drastic lowering of brine-base fluids in drilling as	very marked reaction with fresh water, whi the permeability, the use of oil-base or nd coring operations might be justified. montmorillonite, which probably is respons

Oil and water saturations were determined on several groups of samples; in addition the chloride content of samples containing brine was also measured. In general oil saturations are poor, and if they are true saturations, the sands they represent would be poor producers. It is possible, however, that there was some flushing action by the aqueous drilling fluid during the coring operations. Considerable pressure is needed to circulate the fluid, which tends to force some of the fluid into the formation ahead of the bit as it penetrates. The use of low-loss additives to the drilling fluid would be helpful but would not completely eliminate flushing action. pressure is reduced when the core is brought to the surface. None of the crude oil examined by the author has indicated the presence of much dissolved gas. If this condition holds true in the field, there would be a minimum bleeding of oil from the cores. The water saturation in most of

the cores studied is high, which may support the theory of flushing by the The brine concentrations in the samples studied are low, being on the order of 10,000 parts per million or less of chloride ion. Whether or not this further substantiates flushing by the drilling fluid is not known. he concentrations determined are approximately one fourth of those in most In summary, sands from NPR-4 thus far tested generally have low oil saturation, high water saturation, and low brine concentration. These reults, however, should be interpreted with caution because of the probabilty of flushing by fresh-water drilling fluid and of bleeding of oil from cores. Ordinarily oil-saturation data do not permit prediction as to whether or not a well will be a commercial producer. Tests were made on a sample of crude oil from Umiat Test Well No. 3 to determine whether or not wax saturation existed in the formation. This is mportant, as any solid hydrocarbon in the pores tends to immobilize the oil within the producing sand. The paraffin point of crude from Umiat Test Well No. 3 is 23.5° F, which is about the same as the estimated formation temperature in the sandstone from which the crude was obtained. The producing sand is at a depth of 348 to 359 feet and is in the permafrost zone. Thus t is possible that solid hydrocarbon exists within the oil-bearing formation at Umiat. Tests on the extracted crude from other wells in NPR-4 have not indicated the presence of solid hydrocarbons.

SATURATION

No coring methods can eliminate bleeding of oil from the core if the

Because the ability of a well to produce is a function of the well size, and one method of effectively increasing well size is by shooting, some calculations were made on the shot responsiveness of one of the formaions. Productivity tests were made before and after shooting Umiat Test 3; using these data, the well was found to have an effective shot radius of about 2 feet. This is poor, and was supported by results obtained on cores in the laboratory, where the tendency toward development of fissures and cracks under impact was tested.

The extracts from sand samples from Simpson Test Well No. 1 indicate

that the light fractions are missing from the crude in this area. Qualitatively the viscosity appears to be high, and because the crude is dead, natural production from such a formation would be very poor.

SHOT RESPONSIVENESS OF FORMATION

RESERVOIR PETROGRAPHY OF SANDSTONES By Paul D. Krynine

The sandstones, from NPR-4 belong to the low-rank or normal graywacke class of Krynine; 1/ this class is designated subgraywacke by Pettijohn Low-rank graywackes are characterized mineralogically by the pres-) quartz; (2) abundant chert fragments; (3) a very large amount of white mica and hydromica (muscovite, sericite, and illite), together with chlorite, occurring either as discrete flakes or in fragments of metaedimentary rock, low-rank metamorphic rock such as phyllite and slate, or igh-rank metamorphic rocks such as schist and metaquartzite; and, finally, y (4) a relatively small amount of feldspar (mostly oligoclase with less icrocline) and kaolinite. Metasedimentary rock and low-rank metamorphic rock fragments are compressible and hence during compaction may change their shapes by expanding into pore spaces. Texturally, the graywackes of northern Alaska are characterized by medium grain size (0.10-0.16 mm), extreme angularity and low sphericity of the grains, and very poor sorting. Graywackes in general carry a rather large amount of a "clayey fraction" that consists mostly of finely divided mica and hydromica. The graywackes of the Colville group and the uppermost part of the Nanushuk group contain in addition a large amount of volcanic ash, which introduced more feldspar, montmorillonite, and kaolinite than is

usual in the average low-rank graywacke. Depending on the relative proportions of combined detrital quartz chert, and rock fragments as against the combined finer-grained micas and clay minerals, the graywackes may be represented by sandy, silty, or shaly varieties. Depending on the presence of chemical cements, the graywacke sandstone, siltstone, and shale may be calcareous, siliceous, or phosphatic When stabilization of a shore line takes place, graywackes tend to be winnowed. As the percent of matrix decreases and sorting improves through winnowing, a normal graywacke may pass first into a quartzose graywacke, then into a "protoquartzite," and finally, after considerable reworking, into a "derived orthoguartzite."2/ Averages of texture and composition of the several graywacke types from northern Alaska are given in table 2.

RESERVOIR PROPERTIES Two fundamental properties characterize any sandstone oil reservoir: (1) the capacity to store oil preferentially against water or gas, and (2) the capacity to yield oil by flowage into a well. These properties are unctions of pore morphology, both geometric and physicochemical. Such mass characteristics as porosity, permeability, and saturation are determined by pore morphology. Storage capacity. -- The storage capacity for oil as against water is a notion of relative pore size. In sandstone with an average pore size of 45 microns or larger, oil is stored preferentially against water; or, in terms of mechanical analysis, it is stored in fine sands (diameter 0.25 0.125 mm) as opposed to very fine sands (diameter 0.125-0.0625 mm), which tend to store water. This storage capacity or preferential porosity for oil may have no relation to gross or even effective fluid porosity.

Under the microscope the porosity of a reservoir rock is seen to consist of two elements: (1) visible porosity, represented by openings or pores larger than 10 microns in diameter, that is, pores that can be picked t without undue difficulty in thin section; and (2) residual or "invisble" porosity (capillary or subcapillary), represented by flattish voids and planes of discontinuity between grains rather than by discrete openings. Adequate oil reservoirs have visible pores with a principal mode of not less than 45 microns. This visible porosity is lower than the porosity obtained by physical tests, in some considerably so. A minimum visible porosity of 5 percent is necessary for a consolidated graywacke to be a possible oil reservoir. The residual porosity is difficult to observe visually, but is the difference between the visible porosity and the total measured porosity. This residual or capillary porosity, which can be estimated as inadequate, poor, fair, or good, controls fluid movement and hence deter-

ossible yield .-- The yield of oil from a well depends upon effective , a concept which includes first, adequate rate of flow, and second, maintenance of this rate for a sufficiently long time. The fundamental factor of fluid yield is the morphology of the capillary or residual pores and the physical chemistry of their confining wall areas. graywackes the effective width of the capillaries depends upon the amount of wall area that is coated with hydromica and clay minerals, particularly illite and chlorite. Clean, relatively uncoated pores and capillaries allow a much easier movement of fluids than coated ones. Favorable luid yield is to be expected when less than 60 percent of the channel-wall

Permeability is not permanent or static, but may change, depending upon the reactions between the contained fluids and the wall surfaces of he pores. Certain minerals, such as quartz and chalcedony, are almost completely inert. The finely divided clays and micas, however, may react strongly with fluids that differ in salinity from the fluids present in the formation, which produces swelling and possibly decreases porosity somewhat and permeability considerably. In order of reactivity and propensity toward hydration and swelling, these minerals are: montmorillonite, kaolinte, illite, chlorite, and sericite-muscovite. The reaction and possible damaging action of these clay minerals upon permeability when fresh water is introduced into a reservoir during drilling depend not only upon the type of mineral and its amount but also, to an even greater extent, upon how widely the mineral is distributed within the rock. Hence, widespread wall coatings of montmorillonite and other clay minerals increase the hydra-

tion potential considerably.

RESERVOIR CLASSES A general comparison of the fundamental elements of pore morphology, namely, size of visible pores, amount of visible pore space, and amount of coatings on capillary walls, makes it possible to divide the consolidated sandstone (graywacke) of northern Alaska into four classes of potential oil reservoirs: good, fair, poor, and inadequate. Typical examples from Umiat Test Well No. 1 and South Barrow Test Wells Nos. 1 and 2 (fig. 16) show the variation in porosity and permeability in relation to differences in pore morphology and other fundamental petrographic factors. Percentages given here refer to total number of examined samples and not only to the material in figure 16. Characteristic pore morphology is shown in figures 17 and 18. Good reservoirs. -- Good reservoirs (18 percent of sandstone samples examined) have a visible porosity above 5 percent; an average (principal mode) visible pore diameter of more than 45 microns; and have less than 60 percent of pore and capillary walls clay-coated. The sandstones in the good reservoir class are coarser-grained than most graywackes of northern Alaska; they are characterized by low matrix and cement content, and by relatively small amounts of compressible sand grains. These good reservoirs are either quartzose graywackes (one is almost a protoquartzite) or, at least, normal graywackes considerably cleaned by winnowing. Fair reservoirs. -- Fair reservoirs (24 percent of sandstone samples examined) have more than 5 percent visible porosity, but may be either somewhat low in visible pore size or too high in percent of wall area coated. The measured porosities and permeabilities of this class are not noticeably lower than those of the good reservoir class, but in respect to effective yield or storage the fair reservoir class is definitely inferior. Most these fair reservoirs are graywackes that probably represent a slight shift toward the quartzose pole by incipient winnowing. <u>Poor reservoirs.--Poor reservoirs</u> (20 percent of sandstone samples examined) are considerably deficient in visible porosity (under 2 percent); their average pore size is less than 25 microns; and wall coatings cover more than 60 percent of the wall areas. The measured porosity and perme-

ably would not be economically favorable. Although only 20 percent of the samples studied is of this reservoir class, it constitutes the bulk of the graywackes of northern Alaska. Inadequate reservoirs. -- Inadequate reservoirs (37 percent of the sand-stone samples examined) can neither store nor yield oil; both their pore morphology parameters and physically measured porosity and permeability are very low. The petrographic factors causing these conditions are: (1) a fine sand; (2) too much "clayey" matrix; (3) a particularly unfavorable morphologic distribution of the clayey matter, which produces an excessive amount of wall coating, even if the absolute amount of the matrix is low; t) too many compressible sand grains; and (5) too much cement. All these actors are relative, that is, there may be too much cement for a particular grain size or matrix amount, whereas the same amount of cement would not appreciably affect porosity in a coarser or cleaner sand.

ability of this class is noticeably low, and the reservoir performance prob-

Factors 1 through 4 (and to some extent 5) are primary features that may be eliminated locally, through reworking and winnowing, to produce a "stratigraphic trap." 1/ The author defines sediments by composition and modifies

the compositional terms by texture: low-rank graywackes, as defined mineralogically in the text, occur either as ordinary graywackes (sandstones), or as silty graywackes, or as graywacke 2/ The series "low rank graywacke-quartzose graywackeprotoquartzite-derived orthoquartzite" is produced by purely physical processes. On the other hand, first-cycle orthoguartzites quire considerable chemical weathering prior to physical sorting. These concepts and the exact petrographic definition of these terms are explained in a paper now in preparation by the author.

3/ Illings and Griffiths, unpublished data.

